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ABSTRACT

Examination of newer technology education materials reveals two recurring themes: one relates to curriculum content, familiarizing students with technology, and another to a technique of classroom instruction, i.e., problem solving. A problem-solving framework for technical education has the following components: (1) define the problem; (2) re-form the problem; (3) isolate the solution; (4) implement the plan; (5) restructure the plan; and (6) synthesize the solution. Language plays a significant role in the problem-solving process. Purposeful activity is a central component of problem solving. Teachers play an active part while students are solving problems. There are four kinds of questions teachers employ in helping students to solve problems: (1) memory and recall; (2) grouping or categorizing; (3) transformational; and (4) cognitive leap. Using this process, students solve a problem, develop cognitive and language skills, and become familiar with the technological process, instead of making a "project." By emphasizing an understanding of the process, learners can apply concepts. Teachers should be provided with technological problem-solving knowledge, skills, and activities. (32 references) (NLA)

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Technological Problem Solving

A PROPOSAL

Walter B. Waetjen
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Technological Problem Solving

The last decade has witnessed a startling change in what was once Industrial Arts Education and has now evolved into Technology Education. The evolution has been more than cosmetic, and far more than a simple change of names. Change in the ways students and teachers behave in the laboratory has been effected, in addition to curriculum content emphases. The question is: Are those changes important or are they merely new wine in old bottles? A related question is whether the changes, particularly those concerning instructional techniques, have a strong theoretical basis. This paper seeks to provide answers, even if tentative, to those questions.

Examination of newer curriculum guides that describe and define Technology Education reveals certain recurring themes. One of those relates to curriculum content, another to a technique of classroom instruction. The former theme is to familiarize students with technology so that they may become better citizens and lead a fuller, more informed life. The frequently mentioned teaching methodology is that of discovery or problem solving. Whether or not the emphasis is intended, it remains true that these curriculum guides identify problem solving as a major teaching technique for enhancing students' learning. Even if the authors of these curriculum guides lacked a strong theoretical basis for using problem solving as a key tool for teaching and learning, their choice of words was fortuitous, even inspired.

Problem solving has a rightful place in Technology Education, for a host of reasons. Those reasons derive from a common source—one rooted deeply in the American cultural fabric. Technology is the centerpiece of the American way of life; it is the Pied Piper of our culture and serves as an enticer (Kay, 1973). While technology gives us the means to achieve goals, it neither states nor implies anything about the consequences of those goals. Detractors of technology—and there are some—would say that technology is a god that limps. Limp it may, but it is, nevertheless, the major institution of our society.

The emergence of any new technology is not a mindless, haphazard, chancy event. Douglas (1971) makes the point that emergence of new technology over the centuries had behind it an innovative person who was restless and dissatisfied with their situation and wanted to better it. The end result of that betterment process was a new technology, whether a primitive digging stick or the first of the modern computers. It is literally true that technology is always changing, shifting, modifying itself and helping humans to cope better with their environment, both physical and social. Perhaps that is why technology has always been present in one degree or another in human history.

Individuals and nations seem unwilling, maybe even unable, to freeze technology at a given point and take the position that the "good life" has been achieved. Conceivably, it is because humans always aspire to better health and greater wealth. (Some would say humans are greedy!) That is, humans seek to improve the quality of their lives.

One might even argue that that is one of the major reasons governments and other institutions are created. People aspire to more wealth, however defined, and they need to enhance themselves psychologically and physically. To accomplish these ends requires a better use of available labor, natural resources, and capital. It is technology that satisfies the "better use" requirement. Specifically, it is technological innovation that becomes the agent of change, the leaven that causes societies to behave and believe in ways different from the past.

We do ourselves a great disservice by underestimating the powerful influence that technological innovation has in any society but especially in industrialized societies such as the United States, Great Britain, Germany and Japan, to mention but a few. It is common knowledge that technological innovation produces new gadgets, but not commonly known that it expands human opportunities, improves human productivity, provides greater efficiency in the use of the earth's resources, affects military strength and impacts international trade (Hill and Utterback 1979).

Goldsmith (1970, p. 3) emphasizes these points stating, "Every . . . study has shown that more than half of the

overall growth in national or international product . . . can be attributed to technological innovation." Yet, the influence of technological innovation doesn't end with economic factors for it affects social relationships as well. It becomes a force for social change by altering the nature of human relationships, changing human values, and modifying the character and nature of work. One must be wary of implying that technological innovation is entirely beneficial and has no down-side effects. We know that is not true, just as we know that conflict results from change and causes institutions to struggle for dominance, and sometimes survival.

Care must be exercised not to confuse technological change with technological innovation for while they may be first cousins, they are not identical twins. Technological innovation includes the " . . . creation, design, production, first use and diffusion of a new technological product, process, or system." (Hill and Utterback, ibid., p. 2). In contrast, technological change involves alteration in a production process or product, such as modifying for the better an existing method of production. The key distinction between the two is that technological innovation embodies a *new* product or a *new* method of production. While the distinction may be small and not always easily detected in practice, it is of importance to Technology Education.

In discussing what the United States federal government might do to foster technological innovation, the suggestion has been offered that, "Education of all citizens should be oriented toward developing a capability for problem solving . . . " (Hill & Utterback, ibid. p. 322). The connection deserves emphasis: we must develop problem solving skills in all people so that technological innovation will be optimized. Writing about how to attack the problems posed in technology, another writer Budworth (1973, p. 6) says, "One way of achieving this object is to devote a much higher proportion of the teaching time to case studies and problem solving . . . "

We are, then, left with two major reasons for teaching problem solving in our schools. First, to create a climate of understanding of and receptivity to technological innovation for it has the potential to improve sanitation, communication, housing, food production, disease prevention and treatment, and transportation, all of which improve the quality of life. Second, to develop higher order thinking skills in students. No cognitive skill is more complex than problem solving. It stands at the apex of the hierarchy of all those human skills that can be thought of as thinking skills. Can there be more lofty objectives for education?

Problem Solving

Technology Education, as a curriculum area and as a profession, would appear to have a number of important tasks before it. In all likelihood, the tasks result from the more recent metamorphosis of Industrial Arts into Technology Education. Not the least of the tasks is to achieve some degree of commonality, or uniformity, as to what a student experiences when he or she takes a Technology Education course, say, in the ninth grade. Does a course in Technology Education taken in San Diego, Calif., bear any resemblance to a Technology Education course in Odessa, Tex., or Easton, Md.? Immediately some would cry that a national curriculum is being called for. Not so. Yet, it does seem that credibility—not to mention transferability of credits—would be enhanced if there were some basic similarity of curriculum content that could be agreed upon. This has occurred in other areas such as biology or chemistry and yet there is no rigid national curriculum. As important as that task is, this paper leaves it to another person, at another time, to delineate.

Earlier mention was made of the frequent reference to problem solving in Technology Education curriculum guides. While not a curriculum guide, the recent report of the Technology Education Advisory Council, *Technology: A National Imperative*, identifies problem solving as a major laboratory activity. Specifically, in the chapter "Teaching Technology in Our Schools," mention is often made of problem solving in the elementary school, middle school and high school. Indeed, problem solving is given a center stage position as a method of teaching and as an instrument for learning. The focus on problem solving is exceptionally good, yet a note of caution must be sounded. We must be careful that when we use the term "problem solving" we know the "process" that is problem solving. In other words, knowledge of the word does not automatically mean knowledge of the thing. The balance of this paper will address itself to bringing understanding of the "thing" called problem solving.

Origins of Problem Solving

Inquiry into the nature of problem solving has been with us for a long time. Aristotle speculated about problem solving, but it was not until the latter part of the nineteenth century and the early part of the twentieth century that speculation was joined with experimentation.

Briefly, let us reflect on basic tenets of learning and problem solving as conceived by different schools of psychological thought. At the risk of oversimplifying one can identify three such schools: associationism, gestaltism, and meaning. The oldest of these formulations is associationism which can be traced back to Aristotle and his laws of learning[1] and mental life which held that there were ideas and associations (or connections) between them. Moreover, Aristotle maintained that thinking was a process of movement from one idea to another by means of associations. Over many years refinements have occurred in this approach to thinking and learning so that associationism is regarded now as being based on the principle of reinforcement as learning. Thorndike's classic experiments with animals in puzzle boxes is based on associationism, as is more recent research on anagram solving.

Gestaltism has been referred to as "insight learning," which is a rather sudden reorganization of one's field of experience, such as the flash of insight when one has a new idea or a brainstorm. Thinking, according to this theory, is what occurs when the elements of a problem are restructured in the field of experience (a mental or cognitive phenomenon).

Gestaltists conducted the renowned studies on the role of insight and rigidity in problem solving. Leading proponents of this theory were Koffler (1929), Kohler

[1]Doctrine of association for contiguity; doctrine of association by similarity; doctrine of association by contrast.

(1929), Wertheimier (1945) and Katona (1940). Gestaltists were concerned with creating innovative solutions to new situations while the associationists tried to apply solution procedures from the past.

Associationists believed that problem solving meant trying possible solutions until one eventually worked; but, Gestaltists believed thinking and problem solving was rearranging elements of the problem until the flash of insight occurred. Problem solving, then, to a Gestaltist was the process of searching how one element of a problem related to another element. When that match was founded, there was *structural understanding* or how the requirements of the goal were satisfied by comprehending how parts of the problem fit together.

The "meaning" school of thought about learning and thinking is a refinement of the Gestalt point of view. Proponents of this approach would describe thinking in terms of relating the new information or problem to thoughts or experiences known to the learner. More recently, advocates of the meaning approach have emphasized the role that imagery plays in problem solving.

The meaning view of thinking focuses on determining how a given problem relates to those concepts that are already in existence in the problem solver's memory. Meaning theory added a new dimension to the Gestalt conception by advancing the idea of schemata and assimilation. Schema referred to the organization of previous reactions and how those operate in a satisfactory response by the learner. Assimilation was a searching for the appropriate schema (or setting) in one's previous experience, and when those settings or schema were found, new meaning resulted. In fact, this process became the nub of problem solving.

The foregoing points of view had unique propositions about thinking, learning and problem solving. This paper does not adopt any of those views of problem solving in its entirety, rather, an eclectic position is taken. Adopting such a position might be attacked on the grounds that it lacks rigor, precision, and exactitude. The rebuttal would be that much theory and practice about problem solving has derived from animals in puzzle boxes, humans using nonsense syllable tests, infants stacking blocks, computer simulations of problem solving, and problem solving in mathematics. There can be little quarrel with such studies; each has added something to a growing body of knowledge about problem solving. Yet, what is needed in Technology Education is a distillation or synthesis that will be of aid to those who teach using a problem solving approach.

What is a Problem?

As early as 1910, John Dewey (Dewey, 1910) recognized the importance of defining what was a problem before being able to explain the thought process in problem solving. He believed that a problem exists where the learner is confronted with a "difficulty."

Others have taken a similar position, or, they have altered it somewhat. According to Woodworth and Schlosberg (1955) the individual experiences a problem when he has a goal but there is no clear cut path to the goal. This is very similar to the view expressed by Newell and Simon (1972) that " . . . a person is confronted with a problem when he wants something and does not know immediately what series of actions he can perform to get it" (p. 71). Duncker (1945) believed that a conflict existed between the situation at hand and the desired outcome. Johnson (1955) was of the opinion that a problem was created or experienced by the individual when his first goal-directed response was unrewarded. That is, if behavior is goal-directed and a given behavior(s) does not reach a goal, then a problem exists.

A different position is taken by Raaheim (1974) for he believed that a problem exists when a familiar situation is experienced by the individual with some deviating elements. The so-called deviating elements are referred to as novelty, a concept that arises frequently in regard to the exploratory behavior of humans.

Two authors come close to describing typical classroom situations. Mayer (1983, p. 5) says, " . . . problem should consist of the three ideas that (1) the problem is presently in some state, but (2) it is desired that it be in another state, and (3) there is no direct, obvious way to accomplish the change."

In deciding whether a task really is a problem for students, Charles and Lester (1984, p. 5) offer the following: "*A problem* is a task for which: (1) The person confronting it *wants* or *needs* to find a solution, (2) The person has *no readily available procedure* for finding the solution, (3) The person must *make an attempt* to find a solution." (p. 5).

A summary of these different viewpoints would indicate that:

- There is a goal or an end the individual is directed toward,
- There is some type of conflict experienced when the individual cannot or doesn't attain the goal,
- The individual takes alternative action or reroutes his behavior to get to the goal, and
- The rerouting action or strategy probably is not totally new or novel, but does have elements of novelty in it.

Of those four points, the second deserves additional comment. The conflict experienced by the individual is personal or internal in that it has meaning to the person and is not a conflict as defined by another person. The implications of this point are obvious for teachers who intend to use problem solving as a part of their teaching. The student must attach some personal significance to the problem.

The Problem Solving Process

While curriculum guides and course outlines identify problem solving as a teaching technique, relatively few teachers know how to use it. They cannot be criticized for neither teacher preparation programs nor in-service courses are structured to help teachers learn the problem solving process.

Moreover, teachers have been deterred somewhat from using problem solving as an instructional technique because the areas of investigation have tended to focus on mathematics, business management professionals, nurse educators, architects, engineers, philosophers, and psychologists. None of those helps an elementary or secondary school teacher. A major thrust of these investigations has been to develop heuristics to facilitate problem solving in specific disciplines (Hill, 1979).

Despite these limitations, there is opportunity to develop a strategy or program of problem solving that is applicable to Technology Education. Once that has been accomplished it will be necessary to research *all* aspects of it so that it may be condensed or expanded, modified and rearranged as the research findings indicate. Both aspects are important: development of a paradigm of problem solving and research to test it. These are interactive, or iterative, activities.

Polya (1957) is generally recognized as the person who has done pioneering work in describing the problem solving process. All other formulations appear to follow his ideas, although some have modified it according to their own situation or discipline. The plan devised by Polya has four steps:

1. Understanding the problem
2. Devising a plan
3. Carrying out the plan
4. Looking back

The first step, understanding the problem, was deemed to be critical since it was necessary for the learner to have in mind clearly what was unknown, what data were available, and the conditions they obtained. Later formulations have emphasized the important role that language (discussion) plays in this first step in solving a problem.

Devising a plan, according to Polya, entailed thinking of related problems, data needed to solve the problem, and finding a connection(s) between the data and the unknown. In carrying out the plan of solution, it was advocated that each step be checked carefully and that the learner be able to prove its correctness.

The final step, looking back, is the crux of the process from a cognitive viewpoint, for it requires the learner to examine the solution offered and determine if the result could have been derived differently, or, if either the result or the method might be used to solve another problem. The final step encourages students to transfer learning to other situations through developing cognitive strategies. The work of Polya derived from subjects solving mathematical problems.

Others have had their hand at describing problem solving processes, such as Carpenter (1985) from a school science perspective, King (1981) a business management consultant, Tuma and Reif (1980) speaking from a mathematical position, and DeCorte and Verschaffel (1987) who worked with children in elementary arithmetic. Two other formulations deserve more detailed treatment since their import is relevant to Technology Education.

The booklet by Charles and Lester (1984), while brief, is in a form to be useful to teachers. They describe a ten-step problem solving process that, basically, follows Polya's paradigm; however, the ten steps fit into three time sequences: before, during, and after trying to solve mathematics problems. The "before" sequence required identification of key words and phrases, understanding constraints, and posing possible solution strategies (Steps 1, 2, 3) The "during" sequence examined the proposed solution strategy to determine if it applied to another problem, and whether the proposed solution answered the problem under consideration (Steps 4, 5, 6, 7). "After" sequence activities included student identification of their successful strategies and relating the current problem to previous problems (Steps 8, 9, 10). Students are encouraged to refer to a "Problem- Solving Guide" which is a condensed and simplified version of the ten steps. By referring to the guide, students, it is hoped, will stay on track in moving toward a solution, but recognize they cannot slavishly conform to an outline.

Philpot and Sellwood (1987) come closest to Technology Education in terms of describing a process for the solution of problems. Actually, the authors identify it as a "helpful framework" presumably to emphasize its iterative nature. The framework has nine steps beginning with defining the problem, delineating the constraints, and collecting information about possible solutions (Steps 1, 2). Steps 3 and 4 involve developing possible solutions, and selecting the solution that has the best potential. The action phase calls for tryout of the solution, modifying it if necessary, then proceeding with the optimum solution (Steps 5, 6, and 7). The final steps (8 and 9) call for a description of the final solution. The unique feature of this approach is that the problem to be solved is one of a scientific or technological nature and requires "hands-on" manipulation of tools and materials.

A Problem Solving Framework for Technology Education

The present author's framework embodies a six- step process, none of which is discretely separate from the others. The framework is intended for those who teach Technology Education in laboratory settings. Since problem-solving skills are specific to a given context or discipline, no claim is made that this process could be used in other situations.

Two criteria guided the formulation of this problem-solving procedure; and, they are not mutually exclusive. First, the Law of Parsimony was applied. That is, the process was designed to be as simple as possible without sacrificing essential elements. The more complex and convoluted the process, the more difficulty would be experienced by students in understanding and using it. Second, there had to be a clear-cut provision for designing, diagramming, making, model building and testing.

Step 1
Define the problem

In the typical classroom situation the teacher will in all likelihood present a problem to the class as a whole or to subgroups. An important element of attacking the problem is to ensure that students "own" the problem, i.e. they understand it. To that end, discussion of the wording of the problem, the situation of the problem, and the constraints are highlighted so that students grasp their full meaning and begin to understand how to solve the problem. Through this discussion they learn something significantly different than when they are given the solution (Mayer, ibid., p. 72).

The problem to be solved is one that *must* entail the use of tools and materials. Should it not, then it does not have a proper place in a Technology Education laboratory, even though it might deal with technology. Asking students to design and make a device that automatically operates the gate valve on a settling tank when the level of waste chemicals gets too high fits the aforementioned criterion; asking them to define obstacles to the development of the railroad does not, even though it deal with technological concerns.

A vital aspect of problem definition is the identification of limitations or constraints inherent to the problem or its wording. Such things as the number of variables, conditions, complexity of the wording, and amount of information given will all affect problem difficulty (Charles and Lester, ibid, p. 14). In the settling tank problem given earlier, the teacher added the constraint that the waste chemicals could not be allowed to mix; therefore the valve had to be capable of being operated electrically by the foreman. Conceivably other constraints could have been introduced such as a time limitation for arriving at a solution, the materials or tools permitted to be used, etc. Each of the conditions and constraints has a bearing on the problem and how students may come to understand it.

Should the problem lend itself to sub-problems or substructures, those should be identified in as much detail as possible. At this step, key words or phrases are highlighted. In this case, settling bank, gate valve, operated electrically, are all terms that the students must understand in order to evolve a global understanding of the problem. Discussion is the major means by which problem definition and understanding occurs, even though diagrams might be used.

Step 2
Re-form the Problem

The important aspect of this step is to identify as many solution possibilities as are feasible and testable under the prevailing constraints. Even though there has been much discussion of the nature of the problem, to this point, the correct sequence of actions that will solve the problem is not known to the student. If more information is needed the student will consult knowledgeable people or read books. No matter how much or how little is learned through these sources, it must be remembered that information is anything that reduces uncertainty, the less uncertainty the closer one is to solution to a problem.

There will be a tendency for students to want to come to

closure quickly on a plan of attack or method to solve the problem. Also, there will be a tendency to get lost in a myriad of terms, details, constraints, and other details. If so, it is advantageous to the students to step back, figuratively, go over the elements of the problem rapidly several times to allow a gestalt or total picture to emerge (Tuma and Reif, ibid, p. 6). Then it is possible to state several different solutions or methods by which the problem could be solved.

As a further step to ensuring that students understand the problem, it is appropriate and useful to have them write out the several possible solutions to the problem in their own language. This will foster a will to doubt, to accept premises as tentative, and to free oneself of rigidly held convictions.

Flexibility rather than rigidity of thinking is a hallmark of this step. For the Technology Education student, the identification of different problem solutions allows them to gauge more accurately what might be constructed, what measurements might be taken, and what materials or tools would be needed.

Step 3
Isolate the Solution

At this juncture, the student must isolate from the alternatives developed in Step 2 the solution that will deliver the desired results. Having done that, it becomes necessary to determine how to organize the implementation of the solution so that one may proceed in an orderly fashion. Regardless of whether a student is working alone, in a subgroup, or as part of a whole class exercise, it is expedient to specify the work tasks. This may be done by framing key questions that give direction for action.

Once the work tasks have been delineated, a work plan can be described. It should identify the timing of each task, the person(s) who will carry out the tasks, the models to be built, and the tests that will be taken. Importantly, the criteria of success should be spelled out so that it is ultimately known whether the solution solved the problem.

In general, this step will determine what is to be done and develops a plan for getting it done. It is a time to narrow the options so that the next step may be taken.

Step 4
Implement the Plan

The actions to be taken or operations to be performed so as to solve the problem are taken by the student(s). Each of the work tasks previously defined is carried out in accordance with the work plan. At this juncture layouts are made, models are constructed, tools are used to shape and join materials, and tests are conducted.

Students can become so imbued with the "doing" aspect of problem solving at this stage that they lose sight of the reason for their activity. To offset this the teacher's role is to query students as to where they are in the overall process of problem solving, whether they are carrying out the plan, whether their course of action appears to be leading to a solution, or whether it now seems that an alternative solution would better serve their purposes.

Similarly, when students are applying or pursuing a particular thinking strategy, the teacher will ask whether that strategy might be used on another problem. There are two reasons for doing this, to highlight and bring to the student's awareness the necessity for using cognitive strategies, and to have the student learn that strategies may be applicable to more than one problem.

In summary, this step is the activity phase of problem solving. From a technology viewpoint it is the time when the student's hand becomes the leading edge of his or her mind; when a student has "hands-on" tools, materials and machines, for the very good reason that he or she has had "mind's-on" cognitive processes that lead to solution of problems.

Step 5
Restructure the Plan

This step may not be necessary but probably will since first attempts to solve a problem are frequently unsuccessful. If success is not achieved in executing the initial plan (Steps 3 and 4), then the student will need to restructure the plan or devise an entirely new plan. Eventually, the student could return to Step 2 and select another of the alternative solutions that had been identified. Having done so it will necessitate repetition of Steps 3 and 4. This should not be viewed as a failure or settling for second best for, as Bruner (1966, p. 4) reminds us, "Since learning and problem solving depend upon the exploration of alternatives, instruction must facilitate and regulate the exploration of alternatives on the part of the learner."

In devising and implementing the new plan, the student should be encouraged to think of entirely new strategies, procedures, and tools to solve the problem; and, contemplate using new tests to ascertain results. But before doing so, it is useful to determine why the first plan didn't work and how the new plan will solve the problem. Ultimately, the student must decide on the alternate plan and then implement it.

The plan may have to be restructured several times since problem solving seldom finds a simple, first time solution to emerge. This may cause some students to be disappointed and experience loss of motivation. Yet, this need not be the case for a recent study (DeRoache and Brown, 1987) found that even very young children monitored the success of their goal-directed attempts and tried to correct these errors. The key as to how children perceive this necessity to correct errors and restructure appears to be the classroom climate of learning fostered by the teacher. More will be said about this later.

Step 6
Synthesize the Solution

Finally, the student must determine if the plan worked; that is, did it solve the problem? If the answer is affirmative, the student justifies in writing exactly how the plan and its execution solved the problem. Most importantly, the student should identify the cognitive strategies that were employed since "To be an effective problem solver, the individual must somehow have acquired masses of organized intellectual skills" (Gagne, 1970, p. 233).

No matter the nature of the problem, strategies are

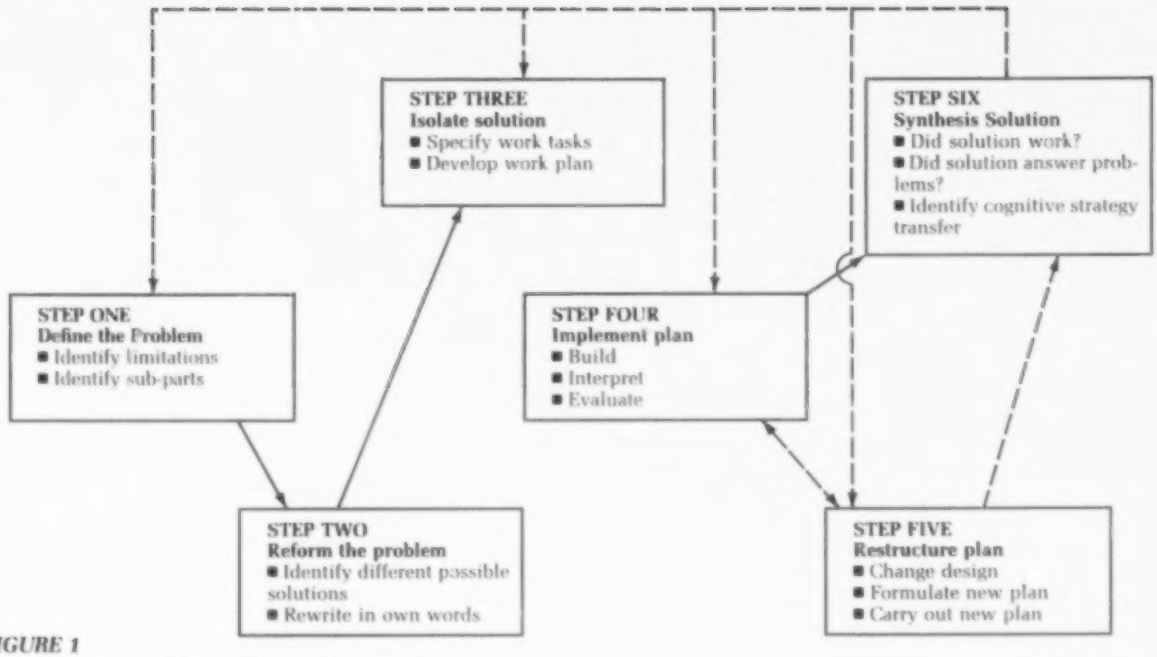

FIGURE 1
An Iterative Model for Problem Solving

important for they are rules that determine how one approaches problem solving, information storage and retrieval, and reading. In synthesizing the student should explicate strategies that worked well and whether they are applicable to other types of problems, and what technological processes were successful or unsuccessful.

This step, then, leads students to consider how their plan (Steps 3 or 5) might have been structured differently, and how implementation of the plan (Steps 4 or 5) might have been done better. The attempt here is to stimulate the learner to develop heuristics, those rule-of-thumb problem-solving methods (cognitive strategies) which often bring success but do not guarantee a solution to the problem.

Admittedly, heuristics are ad hoc methods for solving problems but most of the time most human beings rely on them. It is desirable for students to share with the whole class a number of different strategies for each problem, emphasize them, and attach appropriate labels to them.

Students will be tempted to omit this step, believing their work has been finished with the completion of Step 5. If so, they would have been denied a significant opportunity to learn. Also, the iterative, back-and-forth property of the problem solving process would have been violated.

A diagram of the problem-solving process described in Steps 1 thru 6 is given in Figure 1. Attention is drawn to the fact that it is not to be followed slavishly; rather it is conceptualized and diagrammed as an iteration.

End Note

Any formulation of a problem solving process, and especially one for Technology Education, would be incomplete without mention of the highly significant role that language plays in it. Language is a means of thinking as well as communicating. Since problem solving, learning, and thinking are one and the same thing, it would follow that language in both its oral and written forms is the major tool of problem solving. Language is the most important symbolic tool available as an instrument of thought. One writer underscores this by saying, "It is helpful to talk about your problem at various stages in your search for a solution. Talking to someone may help you to pry loose of . . . constraints . . . . because your colleague . . . may direct you to new avenues of search when he utters a word or asks a question." (Tuma and Reif, ibid, p. 7).

Students are well off to *talk* about the problem confronting them; *discuss* how the problem might be restructured; *write* the plan of attack, *consult* about the reworking of the plan of attack; and *write* a description of the final result and the heuristics involved.

To some it would appear incongruous that a procedure for solving problems in Technology Education would give such high priority to the use of language. Yet, it must be remembered that tools and materials cannot be used properly until they follow what the mind dictates. The hand is the leading edge of the mind, true, but it is equally true that symbols are the pilot of the mind.

The Role of Activity in Problem Solving

One need not search hard or long to justify the use of student activity in the problem solving process. Activity in the sense being used here is actual physical motion, the manipulation of objects or materials. This is not to be construed as random activity such as toe-tapping or gum chewing; rather it is activity directed toward solving a problem that is technological in nature.

One writer (George, 1980, p. 34) makes the point by saying, "Problem solving is greatly facilitated if we can provide as much sensorily-determined information as possible." He goes further by implying that the information

be received in certain ways or contexts. Specifically, he notes, "Then, over and above that, we want to try to provide such information in the most advantageous manner."

Technology Education laboratories have the potential for providing information from many aspects of the sensorium, e.g. the odor of a twist drill that is burning from too many RPM's; the sound of a circular saw blade that is dull, or a motor that is overloaded; and the feel of chatter from a milling cutter improperly mounted.

All too frequently parents have thought of Technology Education as something in which their children make things that are aesthetically pleasing but marginally useful. Even worse, they have thought their offspring manipulated materials for no educative purposes. Kaufman (1984, p. 166) makes an eloquent point in suggesting how activity has a significant role in a problem solving situation when he states, " . . . overt, exploratory activity should not be interpreted as a "blind" random activity. It seems fairly evident . . . that the activity of the subjects should be conceptualized as purposeful and hypothesis-guided search." The hypotheses are, or could be, those that evolve in seeking solutions to a problem.

There seems to be general agreement that purposeful activity is a central component of problem solving. Moreover, it is clear that the activity arises from some prior, or concurrent, thought processes. The activity is not mindless or willy-nilly. It seems strange, therefore, that two writers (Knight and Michelson, 1949) should seem to down play the role of thinking in their recommendations for using the problem solving process. One of these recommendations states, "*Doing* rather than *knowing* should be emphasized." If the hand is the leading edge of the mind it would seem anomalous to emphasize activity over thinking since they are both parts of the parcel of problem solving.

The teacher of Technology Education has a fourfold purpose in using activity in problem solving in his or her laboratory. First, there is the objective of students developing higher-order thinking skills that are inherent in problem solving. This would optimize a student's intelligence and aid him or her in becoming a better learner through the development of as many cognitive strategies as possible.

Second, a teacher would want to teach students about technology as an institution of our society and the way in which it effects their lives. While this may be done in didactic areas of the curriculum, there are certain aspects of it that can be done better in the laboratory.

Third, activity in solving technological problems affords students the opportunity to become familiar with hand tools as well as machine tools, and materials as diverse as ferrous and nonferrous metals to woods and to plastics. In the familiarization process the students might even develop a modicum of skill in using the tools and shaping the materials.

Fourth, a major purpose of the teacher should be to help the student acquire skills of self-instruction (Tuma and Reif, ibid.). Those skills are usually in the form of cognitive activity e.g. the development of strategies and heuristics which help a student to transfer thinking strategies to new situations.

Technology Education, then, not only has a responsibility to use activity as an integral part of problem solving, but it enjoys an opportunity shared with few other curricular areas. There is a built-in opportunity to take advantage of the propensity of human beings to move, to explore, to manipulate and to construct. In short, human beings seem intent upon having some impact on their immediate environment. The impact can be by the use of symbols or by use of activity and tools. Technology Education affords the opportunity to utilize both particularly if problem solving is the mode of instruction as well as the vehicle of learning.

The Teacher's Role in Problem Solving

To introduce problem solving into the Technology Education laboratory means that there will, indeed, be changes in the ways in which teachers structure activities for learners and the manner in which teachers behave. It is fair to say that there will be some change in the content and sequencing of instructional material, in the way in which teachers group students for learning, and in the ways students are evaluated.

Such changes should not strike fear into teachers' hearts, or invite resistance to change. On the contrary, many of the changes will occur naturally as the teacher launches into problem solving as a major instructional technique. The significant change will be in the teacher's attitude about how and what to teach.

Let's clear the air about teaching. It is a complex process and we do ourselves a disservice by oversimplifying it. Good teaching is to be judged more on the basis of what happens moment-to-moment in a laboratory over an extended period of time, rather than on a single lesson no matter how spectacularly taught or brilliantly demonstrated. Good teaching requires that a teacher believe that students want to learn, and that students are valuable simply because they are human beings.

At the operational level the first rule of teaching is to know what you are supposed to teach. The experienced teacher would quickly add a second rule: Know a little more than what you are supposed to teach. Thus, a teacher of technology must have a thorough grounding in technology. Too, the teacher must know the intricacies and mechanisms of the problem solving process in order to guide students to solve technological problems. Finally, the teacher must know students. That is, how students learn, their tolerance for ambiguity, their self-concepts as a learner, analytic ability, and their previous technological background. To know students teachers need information about affective factors, experience factors, and cognitive factors. Getting to know students will be the most difficult task for technology teachers (actually, all teachers) since schools are not inclined in this direction despite the fact that such information could easily be computerized. Schools pontificate about helping teachers to individualize instruction but do little to help them do it.

A major undertaking for the teacher is to create an environment or atmosphere in the laboratory that evokes the greatest amount of thinking from students. This is highlighted by Charles and Lester (1984, p. 29) who claim that, " . . . the classroom climate is so important in developing successful problem solving programs that establishing an atmosphere conducive to problem solving should be the primary goal for about the first two months of the school year."

The very manner in which a teacher presents a problem to students not only partially defines the classroom climate but it influences the success students will have in solving the problem. The teacher's motivation should be to establish a feeling in the classroom of psychological safety and freedom where students are aware of that freedom and are willing to explore any and all ideas that lead to solving a problem.

At first students will be reluctant to do this. They will need reassurance that it is acceptable and desirable to express subjective ideas, and to invent an answer or solution rather than finding it in a book or extracting it from the teacher. Often, the technology laboratory is an ideal setting for students learning to express their personal ideas in a public setting, for the construction project is uniquely the student's own and lends assurance to expressing personal views regarding problem solving. The psychological freedom of which we speak relates to all behaviors connected with problem solving. It does not extend to the license to infringe on another student's rights, person, or property.

Inevitably the question of grouping arises when problem solving is under consideration as a method of teaching. Should one have a single group? Several groups? Individual instruction?What size should subgroups be? Answers depend largely upon the individual teacher and the nature of the problem; however, some guidelines are available. The preponderance of research evidence indicates that group problem solving is in some ways more efficient than individual problem solving, and usually produces higher quality solutions (Williams, 1960).

Another research (Lorge et al, 1955) yielded the same finding and attributed it to the fact that groups asked more questions and obtained more pertinent information than did individuals. With respect to size of groups it has been found (Taylor and Faust, 1952) that groups of two or four were superior to individuals when it came to the number of problems solved and the speed of solution. Also, the larger the group the fewer the number of failures.

The author's caution that groups of four were not twice as efficient as groups of two, nor were groups of two twice as efficient as individuals. Of interest is the fact that group problem solving appears to stimulate greater use of language. Is it conceivable that in technology laboratories where there would be an emphasis on design, construction and assembly that even more usage of language would be found? If groups are used, they should be comprised of students who do not vary too greatly with respect to social dominance, fluency, or intellectual ability (Williams, ibid., p. 18). Notice, again, the necessity for teachers to know the students.

Initially teachers will be somewhat uncertain where to plunge into the maze of problem solving. They will be reluctant to give up the "chalk and talk" or "demonstrate and talk" modes of instruction. While some of the apprehension may be justified—as with anything new—it must be recognized that problem solving is *not* the most efficient means of transmitting factual information. But teachers do this less often nowadays, anyway. Thus, there is a role for lecturing or demonstrations since those techniques impart technological information that may serve as general back ground for a number of problems students will be asked to solve. In other words, lecturing may help students to build up a technological memory bank that is drawn upon when solving technological problems. Emphasis remains on problem solving as the major, but not exclusive, laboratory method of instruction.

That teachers set the intellectual tone or level of classroom interaction is in little doubt. This is evident in the nature of tasks assigned to students, the questions teachers ask, and the type of examinations teachers give. The task of making an aesthetically pleasing "project" is very different intellectually, from solving a problem about technology. Similarly, one type of question is very different from another in the intellectual skills needed to answer them. There are basically four kinds of questions teachers may employ in helping students to solve problems.

Memory and recall questions—These call for the lowest level of intellectual functioning and should be used sparingly. An example is: "What is steel?" To answer, the student goes to his memory bank and gives the correct answer. Sadly, most classrooms are characterized by this kind of question and most teacher-made tests are of this type.

Grouping or categorizing questions—Questions of this type require students to group or categorize information that previously was held separately in memory. For example: "Which of the following are similar or dissimilar and why? Cold rolled steel, brass, tin, hot rolled steel, stainless steel, bronze and copper." Here the learner must go to memory, determine characteristics of various metals, contrast them, and ultimately develop categories according to hardness/softness, or, corroding/noncorroding or color. A teacher is well served to ask questions of this type when students are at Steps 1 and 2 of the problem solving process described earlier.

Transformation questions—To respond to such a question students must change or transform information from one form to another. That is, "Describe a U.S. Standard thread in geometric terms." The student would draw on memory of screw threads and geometry, recognize that a U.S. standard thread is actually an isosceles triangle and then describe how one becomes the other. The conceptual data is the same but the form of representation is not only different but at a higher level of intellectual functioning. Transformation questions would be helpful for the teacher to use at Step 5 of the problem solving process when students have failed in their first solution and are devising another plan. By posing a transformation type question, the teacher encourages the learner to develop heuristics, to seek alternatives that grow out of similarities.

Cognitive leap questions—These questions require one to provide an entirely hypothetical response to a question for which there is no "correct" answer. An example would be: "How would you design and make a settling tank that *separates* waste chemicals before the automatically operated gate valve operates?" Obviously, the dimension added to this question requires considerable extension of cognition into chemistry and related fields.

This type of question is particularly appropriate at Step 6 of the problem solving process when one is identifying the cognitive strategies used to solve the problem, and their applicability to other problems. In this instance the teacher modified the original problem somewhat and caused the student to examine the heuristics used and how they might apply in a related situation.

For a student to respond to a cognitive leap question requires a classroom climate that is accepting of all

attempts to learn, and where ridicule is absent. A laboratory in which cognitive leap questions are frequently used is one in which intellectual functions are high and in which students are willing to take risks.

A concluding note to this section is that teachers play an active part while students are solving problems. The single most important role of the teacher is that of directing student learning by helping with problem understanding, asking questions that extend cognition, suggesting alternatives, inviting discussion, structuring learning groups, and focusing students' attention. By all means, the teacher of technology does not assign a problem, distribute tools and materials, and remove himself or herself from further student contact. To do so is to abdicate the teacher's role in student problem solving experiences.

Teachers' Concerns about Problem Solving

To change the way a person teaches will generate some concerns. A major concern is that of the teacher being removed from the role of provider of information. "Chalk and talk" is comforting, it defines the teacher's role precisely (also the student's) and gives one a sense of purpose and direction. It will take time for the teacher using problem solving to become equally comfortable as the director of student learning.

The Technology Education teacher will be concerned about the students not having a "project" to take home. At first, it will seem a poor substitute that students have solved a problem, developed cognitive and language skills, and will have become familiar with technological processes. However, students will not see these learnings as substitutes, particularly if they have had the opportunity to explain and demonstrate their problem solution to other students (and, ideally, to parents) there will be a high level of satisfaction.

By emphasizing the process, and an understanding of it, learners develop confidence in the ways in which technological concepts can be applied. However, it is desirable to give students some opportunity to produce an object in which both aesthetic and functional satisfaction can be experienced. A student can take home an aesthetically pleasing object and can have used problem solving techniques in its creation. One activity does not necessarily exclude the other; however, it will take a teacher highly experienced in both activities to effect their combination.

A legitimate concern of teachers is "The identification of problems that can be undertaken by a large number of pupils . . . " (Allsop, 1987, p. 183). Here teachers will need help from colleagues, superiors and teacher education institutions. It is unreasonable to think that teachers could shift from one major method of instruction to another without help.

School systems can establish exemplary programs of problem solving that could be observed by other teachers. Teacher education institutions can establish programs of problem solving for in-service teachers on a released-time basis. These programs might even lead to certificates or, over an extended time, a degree.

A model for such an in-service program is offered by the Moray House College of Education in Edinburgh, Scotland. If we expect teachers to develop new teaching skills and change their teaching behavior, they must be given assistance. The assistance would be of two types: providing additional technological knowledge and skills that will be needed for teaching, and technological activity of a problem solving nature that allows one to make full use of technological knowledge.

Conclusion

This paper has sought to develop a stream of thought about the role of technology in society and how it might be taught. There has been an attempt to avoid dichotomies like technology and "high" technology since technology knows no such distinctions. A major premise of this paper has been that problem solving is a process that can and must be taught.

In the abstract technology is a simple process. It runs something like this: An individual wants to do something to improve the conditions of his or her life, so he or she uses whatever resources are available (usually raw materials, capital or personnel) to create a new product or a new method of performing work. This, then, is the process of technological innovation, and makes clear that technology is the result of innovation, not innovation being the result of technology.

If this be true, then the main output of technological innovation is *knowledge*, and more secondarily, an object or gadget. Regarded in this way, technological innovation is a pervasive process in the economic life and well being of nations. For the educator, to view knowledge as the major product of technological innovation is to issue a challenge regarding how instruction is carried on in the laboratory or the classroom.

The major theme of this paper is that technology, by its very nature, is the process of solving problems. Left to their own devices, people may learn to solve problems, however poorly, but as a literate nation we can do better than that. By teaching students how to solve problems of a technological nature, educators can assist all students—boys and girls—to become technologically literate as part of their general education. Problem solving, then, is not just another trick in the technology teacher's bag, problem solving is the *essence* of technology.

To teach students about technological innovation and problem solving encourages them to learn about the development and applications of technology, and its place within their world. Students must learn how their nation earns and maintains its quality of life and standard of living. They must learn that technology affects social relationships, human values, and the very nature of work itself. They must learn to assess the role of business and industry in all of these processes. These learnings enable students to become technologically literate citizens.

Problem solving as an instructional technique has unlimited potential for learning and has for too long been overlooked, disregarded or ignored by educators. But one must be careful not to over bake the pudding for there are some things not known about problem solving. We do not know enough about problem solving activities to match them to age, grade or ability levels. That will have to come through carefully designed research, as will determining how students make steady progress in acquiring the skills and concepts of technology.

While there are unknowns and uncertainties about problem solving, these are far outstripped by its

advantages. From a learning point of view, problem solving allows students with different learning styles to achieve—a matter that has been of concern to teachers for ages. Likewise, it encourages students to take risks in exploration of ideas and solutions. It is this type of intellectual curiosity or exploratory behavior that spells for effective learning; but, interestingly, is the same psychodynamic inherent in technological innovation.

Some educators may worry that problem solving is too open-ended, and that students are left too much to their own devices. Others may feel that problem solving activities often do not result in a tangible, take-home, three-dimensional object. The first concern can be laid to rest easily for problem solving is guided discovery. The teacher has a crucial role in guiding the discovery. With regard to the second concern people in technology education must be cautious about putting too much emphasis on making things, since that could be selling off the family jewels (problem solving) for a night on the town.

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